

Seabed Scattering Model from Low Frequency Reverberation Measurements in Shallow Water

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LONG-TERM GOALS

The long-term goal of this work is: to develop a low-frequency (LF) seabed scattering model from shallow-water (SW) reverberation measurements. The model can be used to predict SW reverberation and echo-to-reverberation ratio in a frequency range of 100-3000 Hz, and to analyze LF seabed scattering mechanisms at low grazing angles (LGA), as well as to extract the LF seabed scattering parameters.

OBJECTIVES

The scientific objectives of this research in FY2011 are: (1) To integrate the energy-flux method for SW reverberation with physics-based seabed scattering models in the angular domain; (2) To derive LF seabed scattering strength as a function of angle and frequency from SW reverberation measurements; and (3) To reveal the physics of the reverberation-derived LF seabed scattering function.

APPROACH

In the past 30 years, one of the major accomplishments in ocean acoustics is the improvement in our understanding of seabed scattering, resulting from significant efforts in both at-sea measurement and theoretical modeling. This progress has summarized in *<High-Frequency Seafloor Acoustics>* [1]. This monograph emphasizes “high frequencies, very roughly, frequencies from 10 kHz to 1 MHz”. Two natural questions are raised from this book: (1) Are those seabed scattering models as well as their physical parameters, which are well developed (and measured) for seabed boundary roughness and sediment inhomogeneity, applicable to LGA at 100-3000 Hz? (2) Are those physical scattering parameters, which are well measured for the high-frequency (HF) seabed scattering models, in same range at LF and LGA? To answer these questions, we need to integrate those physics-based HF seabed scattering models with SW reverberation models for data-model comparisons. We also need LF, LGA seabed scattering data, which are currently in scarce.

LF, LGA seabed scattering is almost impossible to directly measure in shallow water, except through inversion from long-range SW reverberation. However, reverberation inversion requires three elements: a reliable SW reverberation model, calibrated broad band reverberation measurements, and a valid

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seabed geo-acoustic model. Missing of any of these conditions would result in questionable seabed scattering data. Our previous work satisfies these conditions. It is described as follows:

The energy flux method for SW reverberation was first presented three decades ago in archived Chinese journals. These included the closed form expressions for reverberation in SW with a downward refracting or iso-velocity profile [2]. More recently, Harrison and Ainslie have derived nearly identical closed form expressions for reverberation in iso-velocity water [3-4]. Ainslie has referred to these solutions as “the Zhou-Harrison formula” [5]. Thus, we may use these closed-form expressions as a SW reverberation model to extract the LF, LGA bottom scattering strength.

LF sound speed and attenuation in sandy seabottoms have recently been analyzed and summarized from LF long-range field measurements in shallow water [6]. Field measurements conducted at 20 locations in different coastal zones around the world were analyzed. The sound attenuations in sandy or sand-silt mixture bottoms, inverted from different acoustic field characteristics, exhibit similar magnitude and nonlinear frequency dependence below 2000 Hz at all of these sites. The LF field-derived effective seabed geoacoustic model, for both sound speed and attenuation in the sandy bottoms, can be equally well described by the Biot-Stoll model, the Buckingham VGS model, the Chotiros-Isakson BICSQS model, and the Pierce-Carey model; although these four sediment acoustic models consider different physical mechanisms [7]. We believe that our LF effective geo-acoustics model for sandy/silt bottoms, has a solid physics base.

A quality database of reverberation is absolutely essential in derivation of bottom scattering strength from reverberation measurements. However, to get wideband source level (SL)-normalized reverberation level (RL) is a delicate task that can be subject to many sources of error. A prior paper introduced a simple step-by-step measurement technique to avoid the signal overflow and saturation caused by powerful explosive sources [8]. The SL- normalized RL data obtained with this method can be used to derive the LF, LGA seabed scattering.

RESULTS

Benefiting from the accomplishment, summarized in *<High-Frequency Seafloor Acoustics>* [1], we integrated the energy flux model for SW reverberation with physics-based seabed scattering models in the angular domain. This integration directly and intuitively results in a general expression for SW reverberation in terms of seabed physical/scattering parameters, and this expression is identical with the expression derived from the boundary perturbation method [9-10]. The integration of the energy flux method for SW reverberation with the physics-based seabed scattering models has resulted in a simple relationship between the seabed scattering cross-section for a plane wave and the modal scattering matrix for a SW waveguide.

The closed-form expressions for SW reverberation in the iso-velocity waveguide show that the complex seabottom scattering by all modes/rays with different incident and scattering angles can equivalently be represented by the bottom back-scattering at one specific angle. This equivalent relationship is used to derive the bottom backscattering strength (BBS) as a function of angle and frequency. The LF, LGA BBS in a frequency band of 200-2500 Hz and in a grazing angle range of 1.1-14.0° was derived from SW reverberation measurements at three sites with sandy/silt bottoms.

Using our effective LF seabed geo-acoustic model that follows the physics-based Biot model, we get the LF, LGA seabed reflection loss shown in Fig. 1. The sound wave reflection loss from sandy/silt

seabed exhibits an interesting frequency dependence that would affect the frequency dependence of transmission loss (TL), reverberation level (RL), RL-inverted seabed scattering strength, etc. Figure 2 shows that the reverberation-derived LF seabed backscattering strength at the ASIAEX site for grazing angles of $4^\circ, 6^\circ, 8^\circ$ and 10° . This exhibits strong frequency dependence which can approximately be expressed by: $BBS \approx -34.7 + 27.0 \log_{10}(f / 1000)$.

IMPACT/APPLICATIONS

The LF field-derived seabed geoacoustic/scattering models can be used to analyze the physical mechanisms for sound dispersion/attenuation in sandy/sily bottoms as well as scattering from the seabed in a frequency range of 100-2500 Hz. The models can also be used to predict the SW reverberation and sonar performance in this frequency range.

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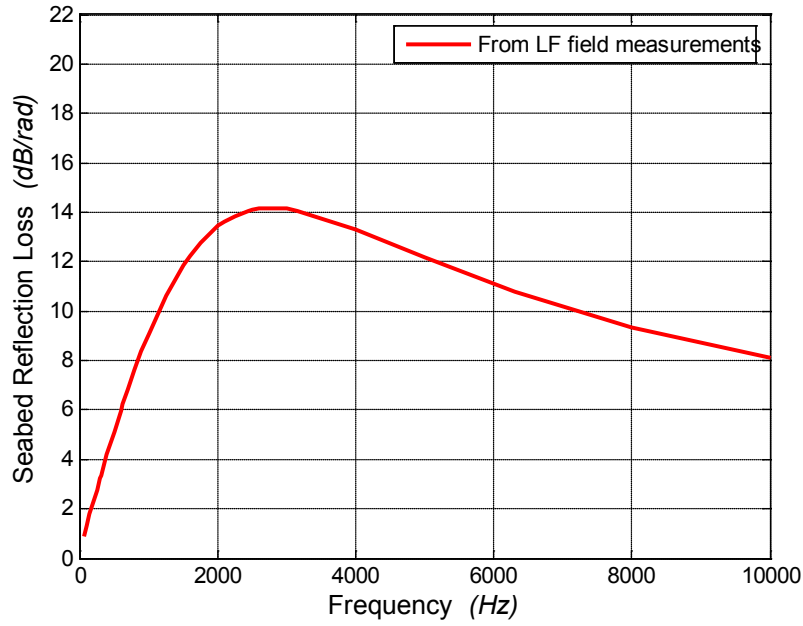


Fig. 1. *The seabed reflection loss as a function of frequency for sandy/silt sea bottoms, derived from the LF field measurements.*

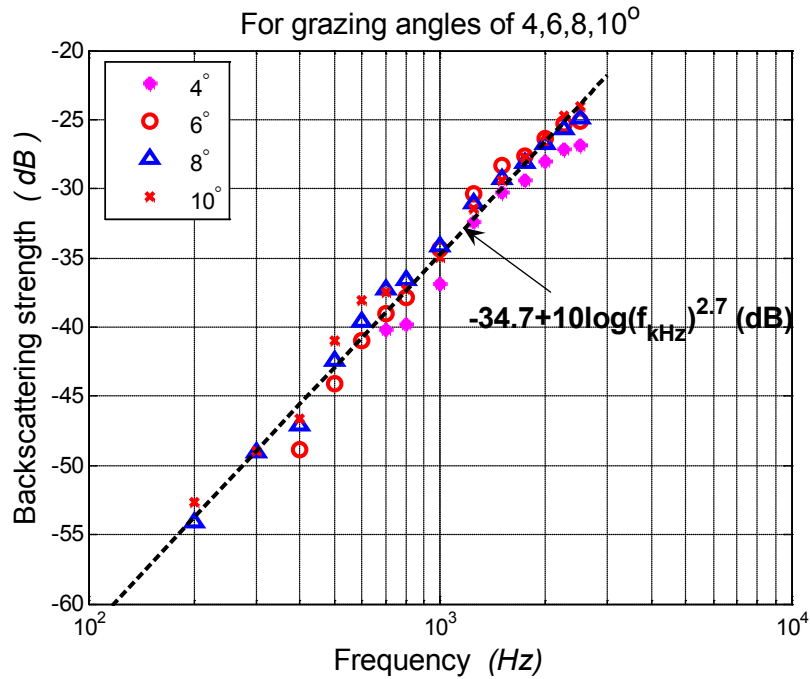


Fig. 2. *Frequency dependence of reverberation-derived seabed scattering at low grazing angles (4°, 6°, 8° and 10°) from the ASIAEX site.2*